The RCNP Cyclotron Facility; Activities of the Experimental Group in 2015

As a national Joint Usage and Research Center, the RCNP Cyclotron Facility provided opportunities for researches, developments and educations in the fields of nuclear and particle physics, astrophysics, nuclear chemistry, nuclear engineering, nuclear medicine, and so on. One of the unique features of the RCNP Cyclotorn is its capability to generate stable nuclear beams as well as the beams of secondary particles such as unstable nuclei, neutrons, and muons, in wide energy ranges up to a few hundred MeV per nucleon. In the following selected topics from the activities in 2015 are presented.

CAGRA Project

We have initiated the CAGRA project at RCNP, Osaka University to perform high-precision spectroscopy of stable and unstable nuclei. CAGRA stands for 'Clover Array Gamma-ray spectrometer at RCNP/RIBF for Advanced research'. This CAGRA project creates a pool of Compton suppressed Ge clover detectors from laboratories in Japan, the U.S., and China which can be assembled to form a CAGRA array at RCNP/RIBF to be utilized for gamma-ray spectroscopy. At present detector inventories are 6 detectors from Tohoku University, 10 detectors from Clover share in U.S. and 3 detectors from IMP in China.

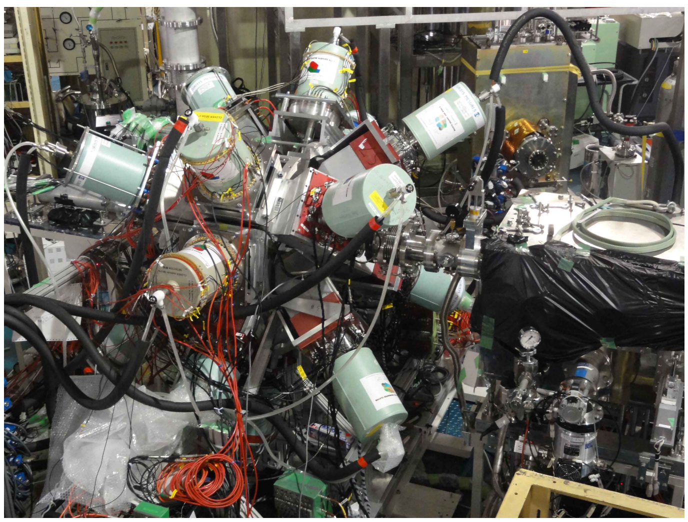

Figure 1: Photograph of CAGRA setup at F3 focal plane of EN beam line.

The CAGRA array is comprised of 16 Ge clover detectors with BGO Compton-suppression shields. Eight detectors are placed at 90 degree, and four detectors are placed at 45 degree and 135 degree each. Figure 1 is a photograph of CAGRA setup at F3 focal plane of EN beam line. This configuration allows for information on gamma-ray angular distributions and correlation measurements while keeping the photo-peak efficiency as large as possible in a close packed geometry. A HPGe clover detector has the capability to enhance the gamma-ray photo-peak efficiency using 'add-back' mode where Compton scattered events detected in 2 or more crystals in the detector can be recovered by adding the signals. Photo-peak efficiency of the array was estimated by a GEANT4 simulation and found to be about 6% for 1 MeV gamma ray after applying the add-back mode as shown in Fig. 2.

At RCNP, a variety of experimental devices can be combined with CAGRA to realize the high-precision spectroscopy. One is the EN beam line where low to intermediate energy RI beams are available. High-quality stable isotope from light-ion to heavy-ion beams can also be utilized for in-beam gamma-ray spectroscopy experiments. Another example is a combination of CAGRA with high-resolution spectrometer, Grand Raiden, where high-precision coincidence experiments with light-ion reactions can be performed. In addition, the high-intensity DC muon beam facility (MuSIC) will be used for the CAGRA experiment.

By coupling other experimental devices with the CAGRA array, various research subjects will be investigated, such as shell-evolution across the chart of nuclei, detailed nature of Pygmy dipole and Gamov-Teller resonances, and characterization of superdeformed states.

In 2015, we have performed a CAGRA campaign experiments at the EN beam line from the end of February to the middle of May. Two experiments utilizing stable isotope beams and four experiment using RI beams have been performed. These experiments with experimental numbers, spokes persons, and the titles are listed below. All experiments have been successfully completed and data analyses is currently on-going.

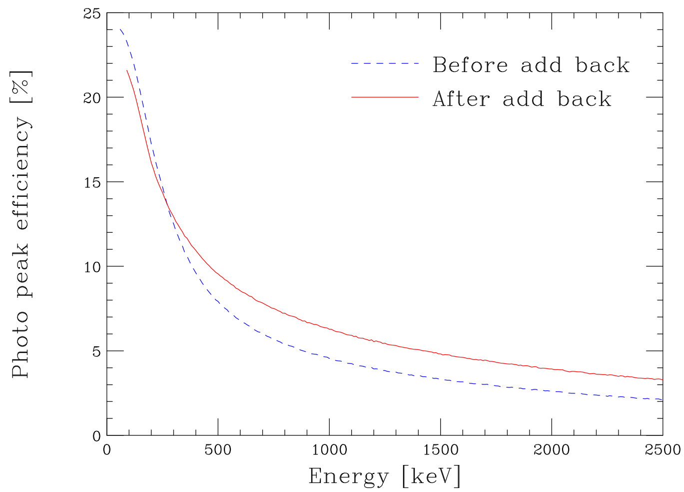

Figure 2: Photo-peak efficiency of CAGRA array estimated by the GEANT4 simulation. Red and blue curves represent the efficiency with and without add-back mode, respectively.

Table 1: A list of CAGRA campaign experiments at EN beam line

Exp. ID	Spokesperson(s)	Title of experiment
E438	E. Ideguchi	Study of superdeformed structure in ^{44}Ti, ^{45}Sc
E448	A. Odahara	Study of high-spin oblate shape isomer by using RI beam induced fusion reaction
E436	M.P. Carpenter	Probing high-spin states in ^{61}Fe using the ^{48}Ca(^{16}C,3n) reaction
E435	F.G. Kondev	Structure of excited states above the long-lived ($T_{1/2} \sim 2.0\times10^5$y), K^π=8$^+$ isomer in ^{186}Re
E437	C.R. Hoffman	Spectroscopy of ^{15}B: A search for unexpected bound states
E439	T.Yamamoto N. Aoi	Study of shell evolution at N=20 in neutron-rich region through nucleon transfer reaction

In 2016, another CAGRA campaign is planned utilizing the Grand Raiden spectrometer. Details of the campaign will be reported in the next annual report.

DC muon facility MuSIC

Beam commissioning and measurements for the new muon beam line, MuSIC-M1, which was constructed in the west experimental hall in 2013, has been performed. The muon beam intensities are 7×10^5 μ/(sec $\cdot$ 1μA-proton) and 1×10^5 μ/(sec $\cdot$ 1μA-proton) respectively for positive and negative charge at 60MeV/c. Surface muons were also observed with its intensity of 3×10^4 μ/(sec $\cdot$ 1μA-proton). The beamline equips a DC separator to separate secondary particles and rotate muon spin for μSR experiments. The separator was well conditioned to apply a HV of $\pm$400 kV with a pure Ar gas. It can work to separate muons and electrons up to 60 MeV/c, so far.

After these beam commissioning, the first data of muonic X-rays from a Cu target was taken by a Ge detector as a demonstration of the non-distractive element analysis with a DC negative muon beam. This successful demonstration was followed by the first user experiment, E411, to develop a new non-destructive elemental analysis of planetary materials. For the material science with μSR measurements, a μSR spectrometer, which had been used at the Tokyo/KEK muon facility (BOOM), has been installed at the end of the beam line. Spin polarizations of the muon beam were estimated from muon spin rotation data in a 40 Gauss magnetic field produced by the spectrometer.

The maximum proton beam current provided for the MuSIC is currently limited at 20 nA. In order to start 1 μA operation from 2016, we prepare renewal of the target system and installation of extra radiation shielding blocks around the beam line.